A COMPARISON OF CONSISTENT VERSUS INCONSISTENT
SCHEDULING RULES IN A FLOW SHOP ENVIRONMENT

THESIS

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Nicola P. Gismondi

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Abstract

A consistent scheduling rule is one which will ensure a job's priority (relative to all other jobs) will remain constant as it moves from queue to queue in a production system. Previous research concerning flow shop priority scheduling rules focused on comparison of either consistent or inconsistent rules. Conversely, this study sought to provide additional insight by comparing consistent and inconsistent rules in a flow shop environment. The Air Force uses both types of rules in maintenance and logistics scheduling. Time and money can be saved if the scheduling managers can better understand the effect of consistency on a system. In order to try to provide some insight on this matter, a simulation study was conducted using The Pritsker Corporation's FACTOR/AIM simulation software. A 2X2 full factorial experimental design was used. The two factors were the level of consistency and type of operating characteristic used. The consistent and inconsistent forms of arrival based and due date based rules made up the 2X2 matrix. A third level of operating characteristic was also tested and discussed. A processing time based rule was tested but could not be included in the matrix because of the failure of the data to meet the assumptions of the required statistical test. Several common performance measures were used to provide a broad range of overall performance comparison. The data was statistically analyzed using a repeated measures ANOVA, Duncan's Multiple Range Test, and a paired t-test to determine whether differences were present. Results indicate that there were statistical differences that may provide some valuable information to scheduling managers. Specifically, inconsistent rules performed better in all cases where a detectable difference was present. Due date rules showed a slight advantage over arrival based rules and processing time rules

appeared to offer the best performance in most cases, although it could not be statistically proven.

A COMPARISON OF CONSISTENT VERSUS INCONSISTENT SCHEDULING RULES IN A FLOW SHOP ENVIRONMENT

I. Introduction

Chapter Overview

In recognition of the importance of effective and efficient use of resources in today's competitive environment, this thesis presents an analysis of scheduling rules that may be implemented by governmental employees in a variety of situations. Whether or not the manager consciously chooses one method over another, scheduling rules of some kind are currently used in most managerial situations. This chapter justifies the analysis by presenting the general issues surrounding flow shop scheduling and demonstrating how the analysis can provide benefit to scheduling managers. A specific research objective and investigative questions are presented, followed by a summary of the methodology employed and scope of the research.

General Issue

Scheduling rules, which include due date setting rules, order release rules, and priority rules or sequencing rules, are rules that managers use to determine the order in which jobs will be processed at each work center throughout a system. For this study, I will use the term scheduling rules to consider only the priority or sequencing type of rules. A flow shop is a system that requires each job to be processed at each work center once and only once. The path from work center to work center must also be identical for every job which moves through the system.

There are several categories of scheduling rules that are commonly used by scheduling managers. Two such categories are consistent rules and inconsistent rules. Consistent rules insure that the order in which a job is processed at each work center remains the same relative to the other jobs in the system. For instance, if a job is the first job in order out of all of the jobs in the system, it will be the first at every machine, and if a job is third in order of all jobs in the system, it will be processed no later than third at every machine in the system. It may be processed first or second at a particular work center if one or both of the two jobs with a higher priority are not present at that particular work center. An inconsistent rule allows the relative processing order to change from work center to work center. One job may be processed ahead of another at one work center, but behind it at the next.

Sequencing rules determine the order of the jobs to be processed by ranking the jobs based on some operating characteristic of the jobs. There are many operating characteristics that can be used depending on the nature of the situation and the objectives of the management. Three popular ones that are used in practice are job arrival times, processing times, and due dates. Arrival based rules include First Come, First Served (FCFS) which ranks jobs based on the order that they arrive at each queue in the system, and First In System First Served (FISFS) which ranks jobs based on the order they arrive at the first work center in the system. Processing time rules include Shortest Processing Time (SPT) which ranks jobs based on the processing time at each work center, and Shortest Total Processing Time (STPT) which ranks jobs based on the total amount of processing time that the jobs will require on their way through the system. Due date rules include Earliest Due Date (EDD) which ranks jobs, at every work center, based on the overall due dates of the job, and Earliest Operation Due Date (ODD) which ranks jobs based on due date of the job's impending operation. The ODD is similar to a regular due date, but an ODD is assigned to each job at each work center. The inconsistent form of the rules are the FCFS, SPT, and ODD. FISFS, STPT, and EDD are the consistent forms.

There has been a fair amount of previous research that compares consistent rules to other consistent rules and inconsistent rules to other inconsistent rules. However, there has been little research which analyzes the effect of consistency on a system or the performance of different types of individual consistent rules against inconsistent rules.

Various kinds of flow shop scheduling rules are currently used in practice. The Air Force maintenance repair and logistics systems operate under both consistent and inconsistent rules. An example of a consistent rule is the priority system currently used in Air Force depots. Priority 1 jobs are always processed first. Lesser priority jobs are processed afterwards as long as there are no priority 1 jobs waiting. By contrast, inconsistent rules are used in the same system when similar types of jobs are processed together at each work center to try to minimize the set-up costs and re-tooling time.

A problem that exists in practice today is that managers not only do not understand how individual consistent or inconsistent rules impact a system's performance, they also do not understand how consistency in general may impact a system. The fact that managers at different levels are motivated and judged using different performance criteria only complicates the situation. Situations may arise where what is best for a particular work center may be in direct contrast to what is best for the overall system under the performance measures being employed. Therefore, it would be helpful to study consistent and inconsistent rules for improving overall performance and setting appropriate performance measures.

The objective of this research is to assess the nature and extent of the performance differences that exist between systems that apply inconsistent rules versus those that maintain consistency across work centers. The specific investigative questions include:

1.) What do previous research results reveal about the effect of consistency in scheduling rules? 2.) How does the performance of consistent rules compare to that of inconsistent rules in general? 3.) How sensitive are the results to changes in system or job characteristics? and 4.) How do consistent or inconsistent rules impact system performance when dealing with multiple performance measures?

A study using the Pritsker Corporation's FACTOR/AIM simulation software will be done to test three types of consistent and inconsistent rules. The differentiation of the three types will be referred to as the operating characteristic (i.e. the job characteristic which is the focus of the sequencing logic). Due date based, processing time based, and arrival based rules of both consistent and inconsistent forms will be tested. The mean and variance of the work in process (WIP), tardiness, age of jobs in the system, and flow time will be used as performance measures. These measures were chosen because they are currently used in practice and provide a broad ranging measure of overall performance. A 2X2 full factorial experimental design will be used, with data on a third level of operating characteristic also being reported. Statistical analysis will be done to detect differences among any of the levels rules or interaction effects that are present between the form of rule and operating characteristics.

Summary

The focus of this research effort was established in this chapter. The shrinking military budget and force structure have elevated the need for effective and efficient use of resources. A clearer understanding of the effect of consistent rules and inconsistent rules will lead to better system performance and better performance criteria to judge scheduling decisions. In this thesis, a research objective and methodology are conceived and executed to help obtain this knowledge.

II. Literature Review

Chapter Overview

Before pursuing the research objective of determining the impact of consistent and inconsistent scheduling rules on a flow shop, relevant information concerning production scheduling should be reviewed. This chapter will discuss the different categories of production research. A brief synopsis of the previous research in the area will be given, along with a discussion of the potential relevance to this study.

Production Scheduling Background

Scheduling can be a very complex process if the goal is to obtain the maximum benefit with the least amount of resources. This is an objective of just about every organization in existence, despite their different situations. To facilitate this objective, information about shop type, type of scheduling rules used, and alternative performance measures has been gathered and evaluated in prior research efforts.

This study will focus on a flow shop. The performance of consistent and inconsistent scheduling rules will be compared in terms of mean and variance of the flow time, lateness, work in process, and age of jobs in an attempt to provide some valuable information to scheduling managers in similar situations. To date there has been little done that involves this type of comparison. Dannenbring wrote, "In recent years many heuristic procedures have been suggested for the flow shop sequencing problem. Although limited comparisons have been made, a full scale test has not been previously reported" (Dannenbring, 1977:1174). He followed by doing a study of eleven scheduling rules, but did not compare the consistent form to the inconsistent form of the rules that were tested. That has been typical of the research that has followed from then to the present.

Although no explicit comparisons have been made, studies of assembly shops, job shops, and flow shops have looked at some of the rules and performance measures of concern in this study. The situations previously studied are different, but there may be some general insight to be gained. Knowledge of the performance of individual rules may be used to formulate an opinion about the comparisons of the consistent and inconsistent rules.

Assembly Shops

There have been a number of studies done in the area of assembly shops. Several involve the same rules and performance that are used in this thesis (Maxwell, 1969; Goodwin and Goodwin, 1982; Russell and Taylor, 1985; Goodwin and Weeks, 1986; Sculli, 1987; Fry, Philipoom, and Markland, 1988). These studies tended to concentrate on the consistent forms of the scheduling rules.

Sculli (1987) compared STPT to SPT and reported that STPT was the dominant rule with regards to the mean and variance of flowtime, lateness, and percentage of late jobs. Goodwin and Weeks (1982) found that EDD outperformed ODD with regards to mean flowtime, mean lateness and percentage of tardy jobs, but ODD had lower variances. In their study, they did not make any more comparisons of rules of the same operating characteristic, using the same performance measure. They simply studied the consistent form of a rule using one performance measure against the inconsistent form of the rule using another performance measure.

There is value to be gained from this research. The types of rules and measures that are commonly used in practice are studied and the performance is reported. However, the studies do not answer the question about the comparison of the consistent and inconsistent form of the same rule using the same performance measure.

Job Shops

There is an abundance of previous research about job shop scheduling. This is probably the largest area of study with regards to scheduling. Many studies have used the previously mentioned rules and performance measures (Conway, March-April 1965; Conway, July-August 1965; Nelson, 1967; Wilbrecht and Prescott, 1969; Fryer, 1975; Kanet and Hayaa, 1982; Elvers and Treleven, 1985; Vespalainen and Morton, 1987; Ragatz and Mabert, 1988; Fry and Philipoom, 1990; Rachmandugu, Nandkeolyar, and Schriber, 1993). This research is about evenly split between the consistent and inconsistent forms of the scheduling rules.

Kanet and Hayaa (1982) reported that ODD outperformed EDD with lower means and variances of flowtime, lateness, and percentage of late jobs. Conway (July-August, 1965) found almost the opposite with EDD performing better on the same measures except for the variance of lateness. He also found that FISFS had a lower mean flowtime than FCFS.

Except for these few studies which directly compared rules, different forms of the same rule have been tested using the same performance measure, but not in the same study. Cross comparisons among studies allow too much room for confounding effects. Therefore, a direct comparison, such as the one accomplished in this study, is needed.

Flow Shops

There has been little done in the flow shop context to compare consistent and inconsistent forms of a scheduling rule. Many studies seek to find the rule that performs best for a given performance measure. First Come First Served, Shortest Processing Time, and Earliest Due Date are the rules commonly studied and used in practice. The other rules are seldom seen in the research.

A few studies include one form of the rules of concern in this thesis (Ow, 1985; Scudder and Hoffman, 1987; Elvers and Treleven, 1985). However, this information will tell nothing of the comparison between different forms of the rule. No studies of flow shops offered a comparison of the consistent versus inconsistent forms of the same scheduling rule.

Summary

In this chapter, an introduction to the different types of production shops was given. The chapter included a discussion about the previous research and the possible links to this study. The value of the present study can also be seen in this chapter because of the lack of research on a direct comparison of consistent and inconsistent scheduling rules in a flow shop environment.

III. Methodology

Chapter Overview

The methodology used in this study will be discussed in this chapter. The simulation model and actual data gathering process will be described and explained. The experimental design will be identified. Finally, the chapter will conclude with a description of the statistical analysis that was done on the data.

Simulation Model and Runs

A simulation model of a flow shop was built using the Pritsker Corporation's FACTOR/AIM simulation software. A number of issues had to be determined before the model could be built. Some concerns included: number of work centers, number of machines at each work center, arrival distribution, processing time distribution, and the due date setting rule.

Before describing the simulation model, it is important to describe some of the assumptions that were made in this model. The assumptions in this simulation included: set up times are negligible, transit times are negligible, no preemption of jobs at a work center, machines do not break down or need maintenance, no labor, tools, or material constraints, and unlimited queue length with no blocking or balking.

Aside from the arrival distribution, the rest of the issues were decided based upon typical practice in the previous research. Therefore, the final model was not based on any single past model, but reflects the synthesis of several models. The queue lengths and utilization rates were key factors used to validate the model as something that could actually be seen in practice.

The final model included five work centers with two identical machines at each work center. These numbers were within the range of 1-10 work centers used in models in past studies. Five work centers and two machines allowed for enough variance in the queues to exploit the difference between the consistent and inconsistent forms of the scheduling rules.

The processing time was selected from a uniform distribution between 1 and 25 hours. This was within the range of previous research and was not extremely important as long an adequate utilization rate and queue length could be achieved. The time between arrivals was chosen to be from a negative exponential distribution with a mean of 6.8 hours. These arrival and processing time distributions provided a system utilization rate in the low ninety percent range and a mean queue length of about 8 jobs. These numbers are comparable to numbers that are seen in practice.

The due date setting rule was similar to the TWK rule that is prominent in scheduling research (Conway, July-August 1965; Goodwin and Weeks, 1982). The amount of total work was multiplied by a factor from a distribution to achieve the final due date. Note that this method creates a relationship between the processing time rules and the due date rules because of the way processing time is used as an input to the due date. The multiplication factor was chosen from a uniform distribution of between 2 and 8 hours, which allowed for about twenty-five percent of the jobs in the system to be late.

Several steps were taken to insure proper simulation runs. First, an initial run was made to validate the model and insure that the queue lengths and utilization rates were acceptable. Next, some pilot runs were done on the model to determine the necessary number of replications and the appropriate warm up time and run length. Based on the formulas in Montgomery (1991:30), thirty replications were calculated to be appropriate for detecting significant differences in shop performance. To determine the warm up time and run length, the average number of jobs in the system was graphed against time. By inspecting this graph, the approximate point that the system reached steady state was determined to be about one year. The simulation was run for five times the length of time it took the system to reach steady state. As a conservative measure, twice the length was regarded as warm up time and therefore was discarded. Three times the warm up length was used as the data collection period. Thus, the model was run for five years and the final three years data was used for the purpose of this study. These runs provided data that could be appropriated analyzed statistically.

The means and variances of four performance measures were collected for each of the scheduling rules. The performance measures included the flow time, work in process (queue time), tardiness, and age of jobs in the system (amount of time all current jobs have been in the system). These individual means and variances were compiled to form an overall mean and variance for each performance measure. The variances of the overall means and variances were calculated. The overall means, variance of the means, overall variances, and variance of the variances will be the key pieces of data that are reported. These pieces of data will be used to establish which scheduling rules offer the best performance on each performance measure.

Experimental Design

This study was constructed with a plan to use a 3X2 full factorial design. However, due to the failure of the data to meet the assumptions of the ANOVA test, a 2X2 full factorial design was used. The processing time based rule was dropped as a level because of the appearance of unequal variances in the data it produced. (Variances that were a power of ten different from the other variances were considered unequal.) Some information based on this data will still be reported, since, in many cases, the differences in the data were so significant that some general conclusions could still be drawn.

The two experimental factors were the form of the rule and the operating characteristic of the rule. The levels of the forms were consistent and inconsistent. The levels of the operating characteristic were arrival based rules, and due date based rules. See Figure 1 for a view of the experimental design matrix. Note that the processing time operating characteristic is included in italics, since it was considered but is not part of the ANOVAs.

	CONSISTENT	**INCONSISTENT**
ARRIVAL		
DUE DATE		
PROCESSING TIME		

Figure 1. Experimental Design Matrix

A matrix of this type will be made for the mean and variance of each of the four performance measures used in this study. The use of this experimental design is very helpful for obtaining the answers to the investigative questions posed earlier. This matrix allows for differences to be highlighted across each row, down each column, and with potential interaction effects.

Statistical Analysis

A repeated measures ANOVA was run on the 2X2 full factorial design. This procedure was done using the SAS statistic software package. This allowed for the differences between the overall means and variances to be detected across levels for each of the performance measures. A Duncan's Multiple Range Test was conducted to compare the overall means and variances for the performance of each experimental block.

Paired t-tests were constructed to determine if any difference existed between the consistent and inconsistent form of all of the scheduling rules. A paired t-test was appropriate because of the use of common random number streams to generate the same set of jobs for each treatment. The main reason that the t-test was constructed was to determine the effect of consistency on the processing time based rule. The differences between the processing time based rules and rules using other operating characteristics could be accepted as significant by inspection since the differences were so great.

Summary

The methodology employed in this study was covered in this chapter. A description of the simulation model and discussion of some of the key issues of the model and simulation were given. The experimental design that was used was discussed along with some reasons for choosing it. Finally, the statistical analysis was explained and justified. The results of the simulation and statistical analysis will be reported in the next chapter.

IV. Results

Chapter Overview

In this chapter, the results from the computer simulation are reported. The outcome of the statistical analysis is also given. This information will be analyzed further and synthesized in the next chapter to highlight some of valuable pieces of information that may be learned from this study.

Simulation Output

The output of the simulation is reported in the following tables. The tables contain the overall means and overall variances, as well as the variances of the overall means and variances of the overall variances. This output is reported for each of the four performance measures of concern in this study. The boldfaced data was used in the 2X2 full factorial design and the paired t-tests were done on the other data. These results will be discussed in the next chapter.

Table 1. Average Tardiness Data

	I	C	
ARRIVAL BASED	**66.43201**	**68.95924**	(MEAN)
	2247.839	**3010.424**	(VARIANCE)
DUE DATE BASED	**30.20041**	**41.57259**	
	1225.243	**2226.11**	
PROC. TIME BASED	61.96479	91.63087	
	1225.243	2144.411	

Table 2. Variance of Tardiness Data

	I	C	
ARRIVAL	9837.77	9457.485	(MEAN)
BASED	6.66E+08	5.97E+08	(VARIANCE)
DUE DATE	3656.163	5187.974	
BASED	2.79E+08	4.75E+08	
PROC. TIME	144,432.10	346,189.70	
BASED	2.26E+11	1.39E+12	

Table 3. Average Flowtime Data

	I	C	
ARRIVAL	303.3647	308.4021	(MEAN)
BASED	5.74E+04	6.46E+04	(VARIANCE)
DUE DATE	260.2177	290.087	
BASED	5.03E+04	6.18E+04	
PROC. TIME	206.60	238.85	
BASED	1.83E+04	2.66E+04	

Table 4. Variance of Flowtime Data

	I	C	
ARRIVAL	13973.2	12798	(MEAN)
BASED	8.21E+08	4.12E+08	(VARIANCE)
DUE DATE	21778.13	29210.46	
BASED	8.18E+08	1.01E+09	
PROC. TIME	177,926.60	416,256.50	
BASED	2.85E+11	1.61E+12	

Table 5. Average Job Age Data

	I	C	
ARRIVAL	151.651	154.0351	(MEAN)
BASED	1430.812	1633.871	(VARIANCE)
DUE DATE	149.8848	173.3586	
BASED	1239.633	1376.932	
PROC. TIME	399.2332	811.6155	
BASED	54771.72	292,387.00	

Table 6. Variance of Job Age Data

	I	C	
ARRIVAL BASED	3656.508	3389.111	(MEAN)
	5.35E+07	2.64E+07	(VARIANCE)
DUE DATE BASED	3300.422	3682.246	
	3.07E+07	3.81E+07	
PROC. TIME BASED	148,757.40	441,797.80	
	3.08E+11	2.05E+12	

Table 7. Average Queuetime Data

	I	C	
ARRIVAL BASED	34.95824	35.78113	(MEAN)
	135.7332	154.2973	(VARIANCE)
DUE DATE BASED	28.64549	33.01921	
	117.9739	145.3035	
PROC. TIME BASED	20.78893	26.00332	
	42.98943	68.33951	

Table 8. Variance of Queuetime Data

	I	C	
ARRIVAL BASED	308.4869	286.9475	(MEAN)
	42999.87	21189.19	(VARIANCE)
DUE DATE BASED	253.8124	296.5034	
	30550.45	42382.5034	
PROC. TIME BASED	154.6562	154.0015	
	10238.87	8049.744	

ANOVA and Duncan's Test Results

This section contains the results from the SAS software output. A 95% level of confidence was used for all of the ANOVA comparisons. The notable findings are reported below by performance measure.

Tardiness The means and variances did not prove to be significantly different across the levels of consistency for this measure. The due date based rules were shown to be statistically superior to the arrival based rules for both the means and variances of tardiness. No interaction effects were present.

Flowtime There was no significant difference between the levels of consistency for the means. The due date based level of the operating characteristic was shown to be significantly better than the arrival based rules for the means. There was no interaction effect present.

The inconsistent variances were shown to be statistically better. The arrival based rules were also indicated to have better variances. However, there was a significant interaction effect for this measure. The Duncan's test indicated that the consistent arrival based rule (FISFS) and the inconsistent due date based rule (ODD) had significantly better performance than their counterparts.

Age of Jobs The mean of the inconsistent level was the only result shown to be statistically better than its counterpart under this performance measure. No difference was indicated between levels of the operating characteristic. There were also no statistically significant interaction effects.

Work in Process There was no difference detected between the consistency level means or variances on this performance measure. The mean due date was statistically better, but there was no difference between the operating characteristic level variances. There were no interaction effects present for this performance measure.

Paired T-Test Results

The following statistical results pertain to the comparison of performance results obtained using a consistent rule with results obtained using the inconsistent rule of the same operating characteristic.

The paired t-tests did not show significant difference at a 99% level of confidence between any of the paired means or variances of the arrival based operating characteristic for any performance measure.

The paired t-tests showed that a significant difference at a 99% level of confidence between the paired means and paired variances of the due date based operating characteristic for all performance measures. The inconsistent form of the scheduling rules was determined to provided better performance.

The paired t-tests showed that a significant difference did exist at a 99% level of confidence between the paired means for each of the processing time rules on all of the performance measures, with the inconsistent version performing best. The paired t-tests of the means of the variances indicated that a difference existed at a 99% level of confidence for the flowtime, tardiness, and age of jobs performance measures. For each level of mean and variance, the inconsistent form of the rule was superior. The means of the variances were not significantly different for the work in process (queuetime) performance measure.

Summary

The results of the study were reported in this chapter. The performance of the scheduling rules from the simulation were documented along with the statistical analysis of this data. These pieces of information will be further discussed and analyzed in the next chapter.

V. Conclusions

Chapter Overview

In this chapter, a synthesis and discussion of the results of this study will be given. The investigative questions will be answered and supported with the results of data analysis. Some interesting findings will be reported and discussed. Finally, this chapter will conclude with some suggestions for further research into this topic and a summary.

Answers To Investigative Questions

In order to assess the nature and extent of the performance differences that exist between systems that apply inconsistent rules versus those that maintain consistency across work centers, the answers to the specific investigative questions are reported below.

Question #1. What do previous research results reveal about the effect of consistency in scheduling rules? As reported in chapter two, there was limited information available to answer this question. The areas of assembly shop, job shop, and flow shop scheduling research have assessed the performance of individual rules in general. However, there were no studies found that were strictly interested in the effect of consistency on a system and few that compared consistent and inconsistent forms of the same rule. This finding supported the need for the present research.

Question #2. How does the performance of consistent rules compare to that of inconsistent rules in general? Unfortunately, there is no all encompassing answer that can be given for this question. The average job age performance measure was the only measure that had a significant result for a difference in means. The flowtime measure had inconsistent rules provide lower variances. These were the only broad findings that could be statistically supported by the ANOVA.

Question #3. How sensitive are the results to changes in system or job characteristics? There were a few cases where one level of the operating characteristic did outperform the other levels. However, these results can only be analyzed on a case by case basis because there was no level that was completely dominant.

The paired t-tests provided some significant results, showing that the consistency factor did have an impact when the operating characteristic was taken into account. The inconsistent form of the rule performed better on more of the measures taken. The inconsistent rules performed better for all of the processing time based rules, with the variance of the queuetime being the only exception. The inconsistent form of the rule was also shown to be statistically better for the mean and variance on all of the performance measures for the due date based rules. There were no statistical differences present for a performance measure between any of the paired means or variances for the arrival based rules.

Question #4. How do consistent or inconsistent rules impact system performance when dealing with multiple performance measures? The performance measure that was used did not have a noticeable effect on the results of the study. This can be observed when the answers to Question #2 and Question #3 are taken into account. There are no cases where the inconsistent form was better on one performance and worse for another. This suggests that the performance measure used was not an important issue to consider. However, there were differences across performance measures with regards to the level of operating characteristic that performed best. The performance measure is presumably important when this factor is considered.

Interesting Findings

One of the most notable findings of this study was the fact that ODD (an inconsistent rule) provided better performance than EDD for the mean and variance on every performance measure. This is interesting because, in practice, EDD is more commonly applied. In part, this may be because organizations experience externally set due dates and it is easier for them to use the EDD logic. It may also be due to the way that the ODD was calculated. A processing time "flavor" was included in the ODD calculation because of the fact that a job's processing times were used as a basis for the operational due dates. However, while an SPT "flavor" might explain ODD's good performance (relative to EDD) on the flowtime and queuetime, it would seem to contradict ODD's good performance on tardiness and job age (two measures on which SPT performed poorly).

Suggestions For Further Research

Some questions emerge from the interesting observations of this study. The answers to these questions could provide valuable information to scheduling managers.

These questions include: 1.) Why do many organizations use the form of the rule that did not provide the better performance? 2.) Did the inconsistent rules perform better because of their ability to better manage local queues? If so, what effect do order release mechanisms have on a system? Finally, 3.) What impact do due date tightness and the ratio of processing time to arrival rate have on the system performance when consistency is a factor?

Summary

The results of the study were synthesized and discussed in this chapter. The investigative questions were answered. Some interesting pieces of information that were found in the study were reported. This chapter concluded with brief suggestions for further research.

<ins>Appendix A</ins>

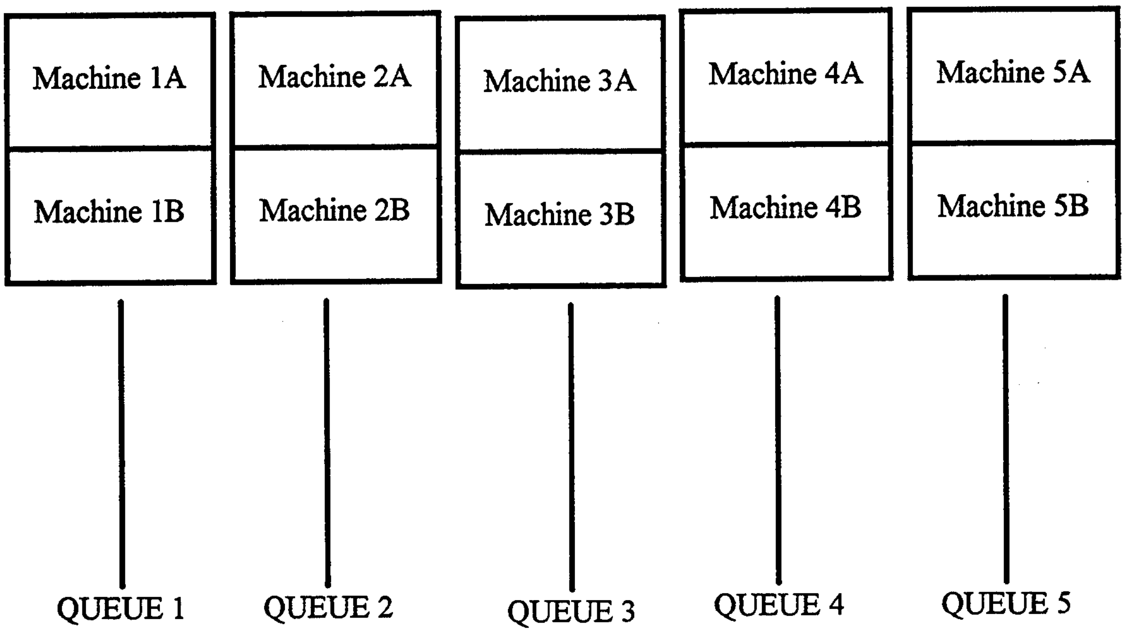

Figure 2. Diagram of Simulation Model

References

Conway, Richard W. "Priority Dispatching and Job Lateness in a Job Shop," The Journal Of Industrial Engineering, 16: 228-237 (July-August 1965).

Conway, Richard W. "Priority Dispatching and Work-in-Process Inventory in a Job Shop," The Journal Of Industrial Engineering, 16: 123-130 (March-April 1965).

Dannenbring, David G. "An Evaluation of Flow Shop Sequencing Heuristics," Management Science, 23: 1174-1182 (July 1977).

Elvers, Douglas A., and Mark D. Treleven. "Job-Shop vs. Hybrid Flow-Shop Routing in a Dual Resource Constrained System," Decisions Sciences, 16: 213-223 (1985).

Fry, Timothy D., and Patrick R. Philpoom. "The Robustness of Selected Job-Shop Dispatching Rules With Respect to Load Balance and Work-flow Structure," Journal of Operational Research Society, 41: 897-906 (1990).

Fry, Timothy D., Patrick R. Philipoom, and Robert E. Markland. "Dispatching in a Multistage Job Shop Where Machine Capacities are Unbalanced," International Journal of Production Research, 26: 1193-1223 (1988).

Fryer, John S. "Effects of Shop Size and Labor Flexibility in Labor and Machine Limited Production Systems," Management Science, 31: 507-514 (January 1975).

Goodwin, Jack S., and James C. Goodwin, Jr.. "Operating Policies for Scheduling Assembled Products," Decision Sciences, 13: 585-602 (1982).

Goodwin, Jack S., and James K. Weeks. "Evaluating Scheduling Policies in a Multi-Level Assembly System," Internal Journal of Production Research, 24: 247-257 (1986).

Kanet, John J. and Jack C. Hayya. "Priority Dispatching With Operation Due Dates in a Job Shop," Journal of Operations Management, 2: 167-174 (May 1982).

Maxwell, William L. "Priority Dispatching and Assembly Operations in a Job Shop," Rand Report RM-5370-PR. Contract No. F44620-67-C-0045. Santa Monica CA: RAND Corporation, October 1969 (AD-697389).

Montgomery, Douglas C. Design and Analysis of Experiments. New York: John Wiley Sons, 1991.

Nelson, Rosser T. "Labor and Machine Limited Production Systems," Management Science, 13: 648-671 (May 1967).

Ow, Peng S. "Focused Scheduling in Proportionate Flowshops," Management Science, 31: 852-868 (July 1985).

Rachamadugu, Ram, Udayan Nandkeolyar, and Tom Schriber. "Scheduling With Sequencing Flexibility." Decision Sciences, 24: 313-335 (1993).

Ragatz, Gary L. and Vincent A. Mabert. "A Simulation Analysis Of Due Date Assignment Rules," Journal of Operations Management, 5: 27-40 (November 1988).

Russell, Roberta S., and Bernard W. Taylor III. "An Evaluation of Sequencing Rules for an Assembly Shop," Decision Sciences, 16: 196-212 (1985).

Scudder, Gary D, and Thomas R. Hoffman. "The Use of Cost-Based Priority Rules in Random and Flow Shops," Journal of Operations Management, 7: 217-232 (October 1987).

Sculli, D. "Priority Dispatching Rules in an Assembly Shop," OMEGA International Journal of Management Science, 15: 49-57 (1987).

Vepsalainen, Ari P.J. and Thomas E. Morton. "Priority Rules for Job Shops With Weighted Tardiness Costs," Management Science, 33: 1035-1047 (August 1987).

Wilbrecht, Jon K. and William B. Prescott. "The Influence of Setup Time on Job Shop Performance." Management Science, 16: B274-B281 (December 1969).

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13. ABSTRACT *(Maximum 200 words)*
A consistent scheduling rule is one which will ensure a job's priority (relative to all other job's) will remain constant as it moves from queue to queue in a production system. Previous research concerning flow shop priority scheduling rules focused on comparison of either consistent or inconsistent rules. Conversely, this study sought to provide additional insight by comparing consistent and inconsistent rules in a flow shop environment. The Air Force uses both types of rules in maintenance and logistics scheduling. Time and money can be saved if the scheduling managers can better understand the effect of consistency on a system. In order to try to provide some insight on this matter, a simulation study was conducted using The Pritsker Corporation's FACTOR/AIM simulation software. A 2X2 full factorial experimental design was used. The two factors were the level of consistency and type of operating characteristic used. The consistent and inconsistent forms of arrival based and due date based rules made up the 2X2 matrix. A third level of operating characteristic was also tested and discussed. A processing time based rule was tested but could not be included in the matrix because of the failure of the data to meet the assumptions of the required statistical test. Several common performance measures were used to provide a broad range of overall performance comparison. The data was statistically analyzed using a repeated measures ANOVA, Duncan's Multiple Range Test, and a paired t-test to determine whether differences were present. Results indicate that there were statistical differences that may provide some valuable information to scheduling managers. Specifically, inconsistent rules perform better in all cases where a detectable difference was present. Due date rules showed a slight advantage over arrival based rules and processing time rules appeared to offer the best performance in most cases, although it could not be statistically proven.

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